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(54) METHOD AND APPARATUS FOR FORMING THIN-WALLED HONEYCOMB STRUCTURES

(71) We, CORNING GLASS WORKS, a corporation organised and existing under the laws of the State of New York, United States of America, of Corning, New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to the manufacture of thin-walled honeycomb structures from extrudable material such as ceramic batches, molten glasses, plastics, molten metals, and similar materials which have the property of being able to flow or plastically deform during extrusion while being able to become sufficiently rigid immediately thereafter so as to maintain structural integrity. More particularly, the present invention relates to an improved extrusion die structure and method for forming uniform thin-walled cellular or honeycomb type articles having a plurality of openings or passages extending therethrough with wall portions between such openings having a preferred thickness of between about 0.002″ and 0.050″, so as to provide open frontal areas of about 75% or greater.

As pointed out in U.S.A. Patent Specification No. 3,112,184, it has been known to make thin-walled ceramic honey-comb structures for use in regenerators, recuperators, radiators, catalyst carriers, filters, heat exchangers, and the like by coating a carrier with a ceramic slurry and binder mix and flowing crimped and flat sheets of such coated carrier together to make a cellular type structure. Although suitable products may be formed in this manner, the prior art technique has not been completely satisfactory due to the fact that cell shape is limited and wall thicknesses may not be uniform, and further the process is relatively slow and requires costly materials.

A further U.S.A. Patent Specification No. 3,406,435 discloses apparatus for manufacturing ceramic elements having a honeycomb structure wherein a plurality of elongated thin-walled sleeve members having extensions with closed end portions are connected to an extruder cylinder. The material to be extruded is forced through the elongated sleeve members and outwardly through orifices formed in side walls of the extensions attached thereto. The sleeve extensions are spaced from each other to provide channels in which the material from the orifices become reshaped into a honeycomb structure.

Although the structure of U.S.A. Patent No. 3,406,435 appears to overcome some of the problems associated with a typical die assembly such as shown in U.S.A. Patent No. 1,849,431 wherein a spider or cross-head positions a plurality of rods, one for each core or cell in the article to be formed; the apparatus is not completely satisfactory for producing honeycomb structures having a multiplicity of sized cells or openings, since not only would it be virtually impossible to construct due to the number of sleeves required, but also the unsupported extensions on such sleeves would have a tendency to distort under extrusion pressures. In addition, as shown in the patent drawings, truly thin-walled structures are not obtainable with such a structure. Further, any variation in the spaces between the extensions will tend to result in a curved extrusion or rippling of the formed article, since a thicker section of the wall will extrude more rapidly than a thin section.

Accordingly, an object of the present invention is to overcome the problem of suspending a plurality of core members in predetermined spaced apart relationship, which has plagued the prior art, by providing a completely unique manner of forming an extrusion die with uniform discharge slots

which are maintained in substantially rigid orientation during extrusion.

It is another object of the present invention to provide a relatively easily manufacturable extrusion die structure for forming thin-walled honeycomb articles having a plurality of openings per cross-sectional area, in which the die structure is substantially rigid so to maintain dimensional stability during extrusion and thereby provide uniform thin walls between such openings.

According to the present invention, there is provided a method of forming a honeycomb structure from an extrudable material, wherein the material is flowed longitudinally through a plurality of feed passageways formed in a unitary die body and, while still flowing longitudinally, is delivered to a grid work of interconnected discharge slots located at one end of the die body and also formed integrally therewith, wherein the longitudinal flow of extrudable material through the discharge slots is impeded as compared with its flow through the feed passageways so as to promote lateral flow of extrudable material within the discharge slots and to form a unitary grid-like mass throughout the discharge slots before longitudinally discharging the grid-like mass from the die body as a honeycomb structure.

The invention also provides an apparatus for forming a honeycomb structure from an extrudable material comprising an extrusion die having a unitary die body with a plurality of feed passageways formed integrally therewithin, such passageways extending longitudinally through the die body from an inlet face at one end thereof and terminating at a plurality of discharge slots located at the other end of the die body, the discharge slots being formed integrally with the die body and extending inwardly from an outlet face at the other end thereof; the feed passageways being connected to root portions provided at the inward ends of the discharge slot so that extrudable material fed through the feed passageways will be delivered to the interconnected slots; the discharge slots having a resistance to material flow greater than that of the feed passageways and sufficient to ensure that the material will flow laterally as well as through the depth of the discharge slots to form a unitary grid-like mass before being discharged from the die body as a honeycomb structure.

The extrusion die will form thin-walled cellular or honeycomb structures. Cellular or honeycomb structures refer to any structure having a plurality of passeges of any desired size or shape extending therethrough, whereas thin walls refer to the walls between such passages having a thickness of from 0.002″ to 0.050″. The extrusion die is preferably of a unitary construction having a plurality of interconnected discharge slots provided with uniform openings in an outlet face of the die. The discharge slots may either be uniformly spaced-apart or formed with variable spacing therebetween if desired, and the gridwork formed in the outlet face by such slots may be of virtually any geometric pattern such as square, rectangular, triangular, hexagonal and circular. The feed passageways, communicate between the inlet face of the die and inner root portions of the discharge slots to deliver extrudable material from an extrusion chamber to the discharge slots. The feed passageways intersect selected portion of the gridwork formed by the interconnecting discharge slots.

The discharge slots, which are of a predetermined size and orientation to form a desired thin-walled structure, extend inwardly from the outlet face a distance sufficient to ensure the lateral filling of all outlet portions of such slots with the extrudable material delivered thereto by the feed passages, prior to such material being discharged from the die. In order to facilitate such lateral flow of batch material within the discharge slots so as to provide a coherent mass of such material within the gridwork formed by the interconnected discharge slots, the discharge slots are formed with a greater resistance to batch flow than that provided by the feed passageways. The resistance to flow in the slots must be sufficient to ensure that the batch material will flow laterally within as well as through the discharge slots and prior to discharge therefrom form a continuous mass of interconnected batch prior to such discharge. Further, the root portions of such discharge slots may be contoured to provide ease in lateral flow.

Although the die body is preferably produced as a unitary construction so as to provide the required strength and rigidity to withstand extrusion pressures without failure or deleterious deformation, the body *per se* may be formed either from a single piece of material or from a plurality of pre-formed sheets which are subsequently fused or bonded together to form a unitary body. However, where the extrusion pressures are not excessive, such sheets may merely be clamped together. A collar member may be provided about the die body to form a bounding orifice about the periphery of the outlet face, so as to provide for an integral shell about the honeycomb structure. A plurality of longitudinally-extending feed passages are formed in the die assembly to feed batch material to the bounding orifice, and restriction means may be provided to vary the resistance to flow through such passage.

In the accompanying drawings:

Figure 1 is a top plan view of a die assembly embodying the present invention,

Figure 2 is an elevational view in section taken along line 2—2 of Figure 1,

Figure 3 is a bottom plan view of the die assembly shown in Figure 1,

Figure 4 is a greatly enlarged fragmental top plan view of the embodiment shown in Figure 1 illustrating the orientation of the feed openings and discharge slots,

Figure 5 is a top plan view of a further embodiment,

Figure 6 is a top plan view of an additional embodiment,

Figures 7, 8 and 9 are fragmental cross-sectional views in elevation illustrating various forms of discharge slots which may be utilized with the disclosed die structures.

Referring now to the drawings, and particularly Figures 1 to 4 inclusive, a die assembly 10 is shown comprising a die body 12 and a collar 14. The die body has an inlet face 16 provided with a plurality of feed passageways 18 for feeding batch material to the matrix of a honeycomb structure, as well as a plurality of annularly arranged feed passages 20 for feeding batch material to an outer shell for such structure. If desired, a circular feed slot could be substituted for the feed passages 20, and the resulting central die portion held in position by suitable pins or the like.

The die body 12 has an outlet face 22, opposite inlet face 16, which is provided with a plurality of interconnected discharge slots 24. As shown in Figure 3, the interconnected discharge slots 24 form a gridwork through which the batch material is extruded to form the matrix of a coherent honeycomb structure. Each discharge slot 24 is provided with a root portion 26 at its inward end, and the feed passageways 18 communicate with selected areas of such root portions. As shown in Figure 4 the feed passageways 18 communicate with alternate intersecting slots formed in the discharge gridwork, such that the feed passageways intersect one set of diagonal corners of core pins 28 formed by the intersecting slots. As shown particularly in Figure 2, the feed passageways 18 have a taper 30 at their lower ends which intersect the root portions 26 of slots 24. The relatively large area of intersection as shown in Figure 4 helps to provide for lateral flow within the slots between the intersections thereof with adjacent feed passageways 18, so as completely to fill the lateral extent of the slots with batch material prior to the discharge thereof from the slots, even though a portion of the batch material directly below the feed passageways longitudinally flows directly through such discharge slots. The discharge slots 24 extend inwardly a sufficient distance to ensure the filling of at least the outlet end of the slots through lateral flow of the batch material prior to the discharge thereof from the gridwork formed by such slots. The resistance to batch flow necessary for encouraging lateral flow will of course not only be affected by the viscosity of the extrudable material, but also by the depth of the slots through which such material must travel during attainment of lateral flow. Preferably the resistance to batch flow in the slots should be at least equal to that in the feed passageways, however, satisfactory results have been obtained by providing the slots with from 0.8 to 6 times the resistance to flow through the feed passageways.

As shown particularly in Figure 2, the collar member 14 may have an adjustable insert 32 threadably attached thereto. The lower inner periphery of insert 32 forms an annular orifice 34 with the outer periphery of outlet face 22. Feed passages 20 supply batch material to the annular orifice 34 to provide an integral shell about the honeycomb matrix formed by the gridwork of discharge slots 24. The adjustable insert 32 has an upper tapered surface 36 which cooperates with outwardly tapered surface 38 formed on die body 12, to vary the resistance to the flow therebetween of batch being fed to the annular orifice 34. That is, the resistance to the flow of batch material being delivered to the annular orifice 34 may be varied by threadably adjusting the position of insert 32 within collar 14. Not only do the tapered surfaces 36 and 38 provide a means for varying the resistance to flow, but also permit the annular rig of feed passages 20 to be outwardly offset and thereby permit the positioning of a full complement of feed passageways 18 for uniformly feeding batch material to the gridwork of interconnected slots 24.

Although a rectangular gridwork is shown being formed by discharge slots 24 in Figures 3 and 4, the core pins 28 formed by slots 24 may be of a square configuration as shown in Figure 5. Further, if desired each intersecting slot 24 may be provided with a feed passageway 18 as shown in Figure 5, rather than at every other intersection as shown in the embodiment of Figure 4. The gridwork formed by the intersecting slots may be of virtually any desired pattern, including such geometric shapes as round, square, oblong, triangular or hexagonal. Honeycomb structures for use as heat exchangers, for instance, may be in the form of long thin passages formed by a plurality of thin parallel walls having only periodic perpendicular webbing walls for maintaining the spacing between such parallel wall.

As shown in the additional embodiment of Figure 6, the discharge slots 24 may be fed by feed passageways 18 in the form of longitudinal passageways, rather than by circular passageways as shown in the embodiments of Figures 4 and 5. It will be apparent, however, that the longitudinal feed passageways 18 formed in the inlet face of the die body shown in Figure 6 must be out of

register with the discharge slots 24 formed in the outlet face, so that the core pins 28 are not weakened excessively. Accordingly, it is felt that although longitudinal feed passageways may be utilized if desired, circular feed passageways have an advantage over longitudinal feed passageways since a more rigid structure is usually obtained. As previously mentioned, the feed passageways need only to be located such that the feed to the slots is uniform, since the extrudable material must flow laterally from the feed passageways to completely fill the slots in the die prior to discharge from the outlet face.

Referring now to Figures 7, 8 and 9, the various forms of slot configurations are shown which may be utilized with the die structures of the present invention. Although the various slot configurations may be formed in a unitary die block by applying conventional machining and cutting techniques, or through the use of electric discharge machining, the slots are illustrated as being formed in a plurality of sheets which may be individually machined, stacked together, and then formed into a unitary body such as by clamping, brazing, or diffusion bonding. Similarly, their associated feed holes may be formed either before or after bonding. Slot 24*a*, is shown in Figure 7 as being equally formed in two opposing sheets 40, in such a manner that the root portion 26 has a larger cross-section than the same cross-section of the discharge opening in outlet face 22, and the opposed sidewalls gradually taper inwardly from the root portion to the outlet face.

In a like manner, Figure 8 illustrates a slot 24*b* being equally formed in opposing sheets 40 and having an enlarged root portion 26 as compared with the discharge opening in outlet face 22. However, the opposed sidewalls of the slot 24*b* initially taper inwardly from the root toward the outlet face but have a parallel section adjacent such outlet face. Figure 9 illustrates a slot configuration 24*c* wherein one wall of the slot is formed by an uncut wall of a sheet 40 whereas the opposite wall is formed with a taper and is formed in an adjacent sheet 40. If desired, the slot 24*c* could be provided with a parallel opposing wall portion adjacent the outlet face 22. Further, any of the slots 24, 24*a*, 24*b*, or 24*c* and their associated feed passageways could be formed within a unitary or laminated die body by means of chemical machining as disclosed in U.S.A. Patent Specifications Nos. 2,628,160, 2,684,911, and 2,971,853. Such chemical machining would also be useful in forming a plurality of intersecting circular discharge slots.

The particular material utilized to produce the die body will of course be predicated upon the material to be extruded therethrough. The dies, for example, may be manufactured from machinable metals such as aluminium and cold rolled steel, or vitreous and ceramic materials such as glass ceramics, tungsten carbide and alumina. Although the utilization of slots having contoured roots for facilitating the lateral flow of batch material therewithin has been disclosed, it has been found that straightsided slots 24 as shown in Figure 2 are very adequate for extruding ceramic batch materials.

As will be noted in Figure 3, some of the core pins 28 about the periphery of the outlet face 22 are of a reduced size due to the circular configuration of annular orifice 34. However, by shaping the outside casing produced by orifice 34 so that wall portions thereof are parallel to the slots formed in the outlet face, all of the core pins may then be formed of an equal size. For example, if the orifice 34 is formed with a square opening, and the outlet face is provided with a grid-work having a square slot pattern, all of the core pins may be of equal size. Further, if the orifice 34 is provided with a hexagonal opening and a triangular slot pattern is formed in the outlet face of the die, all of the core pins will be of equal size since the gridwork will coincide with the shell configuration.

Although the feed passageways 18 are usually uniformly drilled within the die body to intersect with selected areas of the slots forming the discharge gridwork, the diameters of the various feed passageways may be varied in selected areas to provide greater or less feed as may be necessary due to the particular configuration of the extruded cellular honeycomb article. Even though the utilization of longitudinally extending feed passageways is preferred, it may be desirable to slant feed passageways in the area of the collar in order to provide complete batch filling adjacent the shell. Further, although the invention is primarily useful in overcoming the problems of forming thin-walled honeycomb structures having from about 60 to 600 openings per square inch of cross-sectional area, it should be appreciated that it may also be used in making thick walls if desired.

It will be readily apparent to those skilled in the art that the particular size and shape of individual orifices will vary with the physical properties of the material being extruded, and although the present invention is not directed to extrudable batch materials *per se*, but rather to a method and apparatus for extruding honeycomb articles, the following specific example is given merely as being one illustration of the invention.

A 5″ diameter die having an overall thickness of 1.2″ was made from cold rolled steel and provided with a surrounding collar mem-

ber. A gridwork of discharge slots was cut into the outlet face thereof with a width of 0.010 inches and a depth of 0.150 inches forming square core pins having a width of 0.065 inches. Feed passageways having a diameter of 0.081 inches were drilled into the inlet face of the die to a depth of 1.05 inches so as to intersect the discharge slots adjacent every other intersection of the gridwork, thus producing 89 feed passageways per square inch of cross-sectional area. The slots had a relative resistance to flow of about 4 times that produced by the feed passageways. Also a circle of feed passageways for the shell were drilled with a diameter of 0.070 inches and a depth of 0.900 inches to form a total of 72 feed passageways for feeding batch to the annular orifice formed between the die body and collar member.

A ceramic batch material comprising about 58 parts by weight of pulverised EPK Florida Kaolin, obtainable from Whittaker, Clark and Daniels of New York, N.Y., about 20 parts by weight of Texas white talc #2619, obtainable from Hammel & Gillespie, Inc. of White Plainfield, N.J., about 22 parts by weight of T-61 alumina produced by Aluminium Corp. of America, and about 28 parts by weight of water, with suitable extrruding aids for bonding and plasticizing such as methyl cellulose, was fed to the die under a pressure of about 1900 *psi* at an extrusion rate of about 45 inches per minute. The batch material flowed longitudinally through the feed pessages and was delivered to the interconnected discharge slots forming the square-patterned gridwork, whereupon a portion of the material flowed laterally within the gridwork to form a continuous grid-like mass therewithin. Batch was simultaneously fed to the annular orifice surrounding the grid-like mass, and then the interconnected mass was longitudinally discharged simultaneously from said slots and said orifice to form a honeycomb structure with an integral shell. The resulting structure had 179 openings per square inch with wall members therebetween of 0.010 inches, thus producing an open frontal area of about 75%. Both the cells and the bounding wall members were uniform throughout their cross-sectional and longitudinal extents. It will be appreciated, that after the ceramic structure was dried and fired, the resulting wall members had a thickness of even less than 0.010 inches thus resulting in a truly thin-walled honeycomb structure having both uniform wall portions and cells.

WHAT WE CLAIM IS:—

1. A method of forming a honeycomb structure from an extrudable material, wherein the material is flowed longitudinally through a plurality of feed passageways formed in a unitary die body and, while still flowing longitudinally, is delivered to a grid work of interconnected discharge slots located at one end of the die body and also formed integrally therewith, wherein the longitudinal flow of extrudable material through the discharge slots is impeded as compared with its flow through the feed passageways so as to promote lateral flow of extrudable material within the discharge slots and to form a unitary grid-like mass throughout the discharge slots before longitudinally discharging the grid-like mass from the die body as a honeycomb structure.

2. A method according to Claim 1, wherein a portion of the extrudable material is passed directly through the discharge slots.

3. A method according to either preceding claim, wherein the extrudable material is also passed through an orifice surrounding the discharge of the unitary grid-like mass while varying the resistance to flow through such orifice to form an integral shell for the honeycomb structure.

4. A method of forming a honeycomb structure from an extrudable material substantially as described with reference to the accompanying drawings.

5. An apparatus for forming a honeycomb structure from an extrudable material comprising an extrusion die having a unitary die body with a plurality of feed passageways formed integrally therewith, such passageways extending longitudinally through the die body from an inlet face at one end thereof and terminating at a plurality of discharge slots located at the other end of the die body, the discharge slots being formed integrally with the die body and extending inwardly from an outlet face at the other end thereof; the feed passageways being connected to root portions provided at the inward ends of the discharge slots so that extrudable material fed through the feed passageways will be delivered to the interconnected slots; the discharge slots having a resistance to material flow greater than that of the feed passageways and sufficient to ensure that the material will flow laterally as well as through the depth of the discharge slots to form a unitary grid-like mass before being discharged from the die body as a honeycomb structure.

6. An apparatus according to Claim 5 having collar means positioned about the die body and forming an orifice about the outer periphery of the outlet with extrudable material being fed also to the orifice.

7. An apparatus according to either of claims 5 and 6, wherein the root portions of the discharge slots have a cross-section

greater than the corresponding discharge cross-sections at the outlet face.

8. An apparatus for forming a honeycomb structure from an extrudable material substantially as described with reference to the accompanying drawings.

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1405618 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

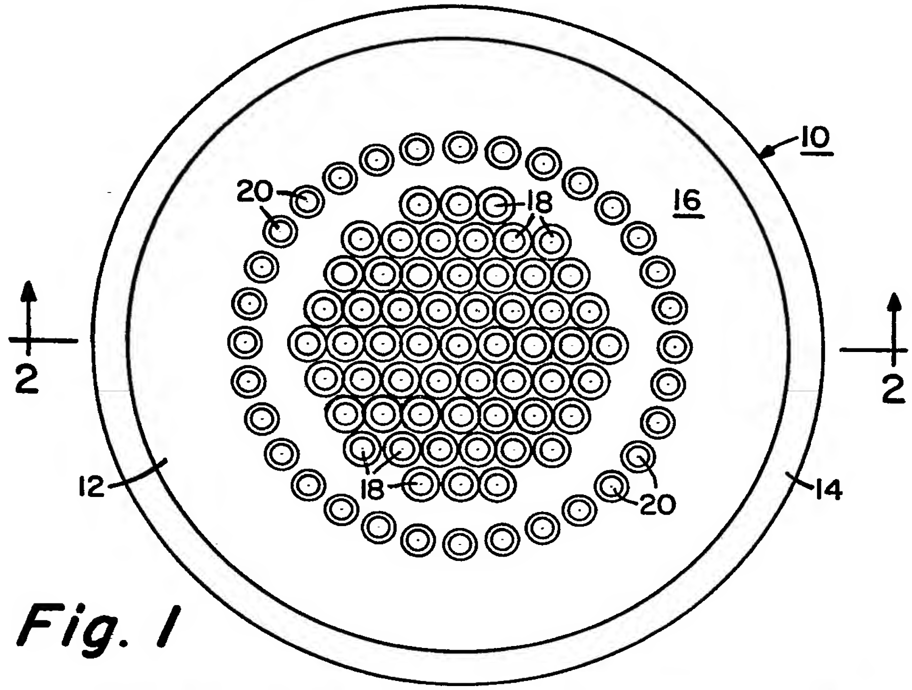


Fig. 1

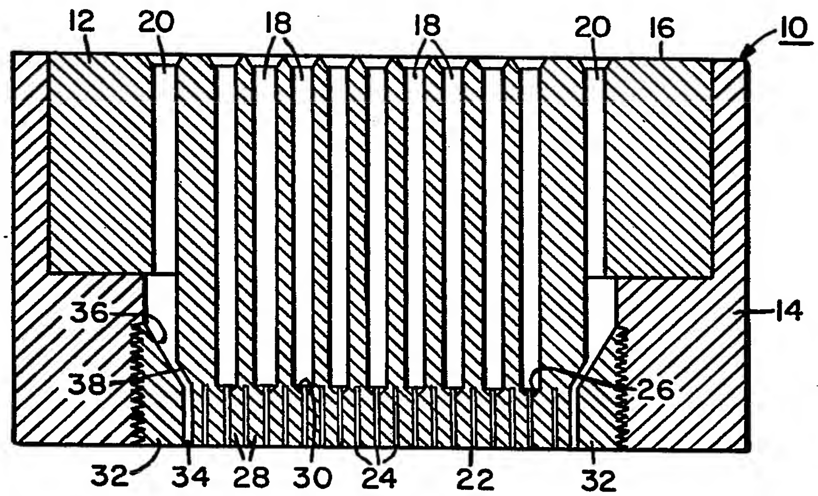


Fig. 2

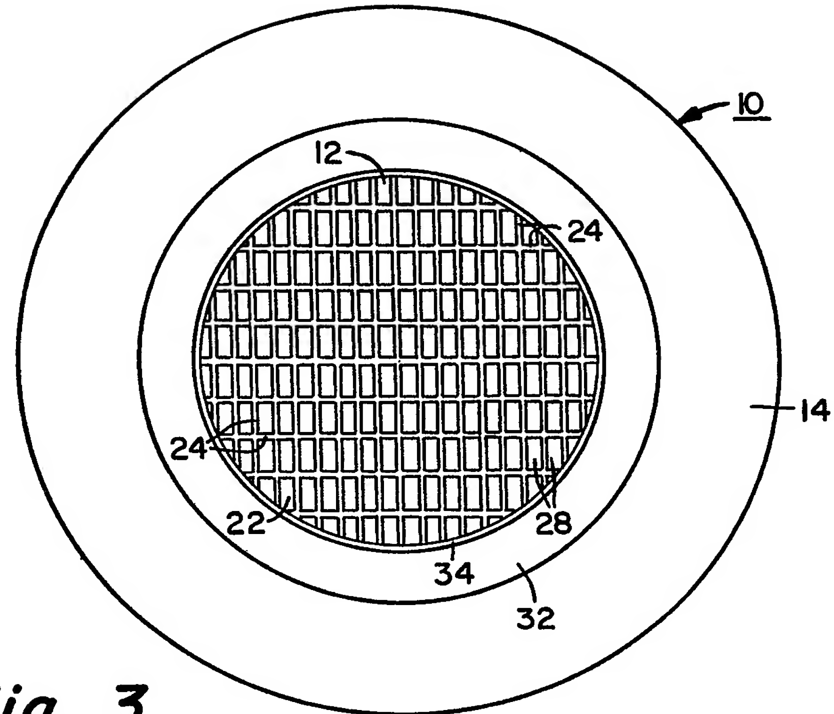


Fig. 3

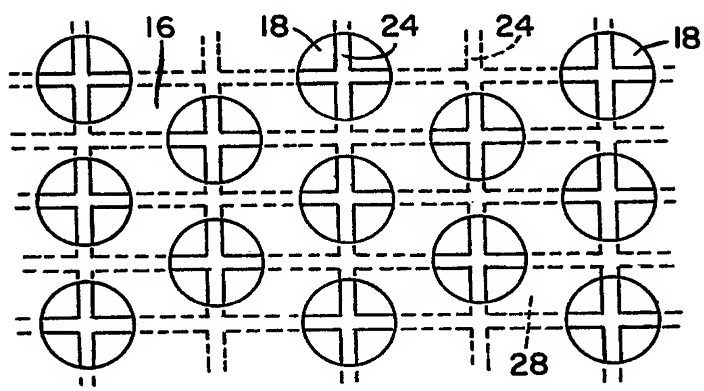


Fig. 4

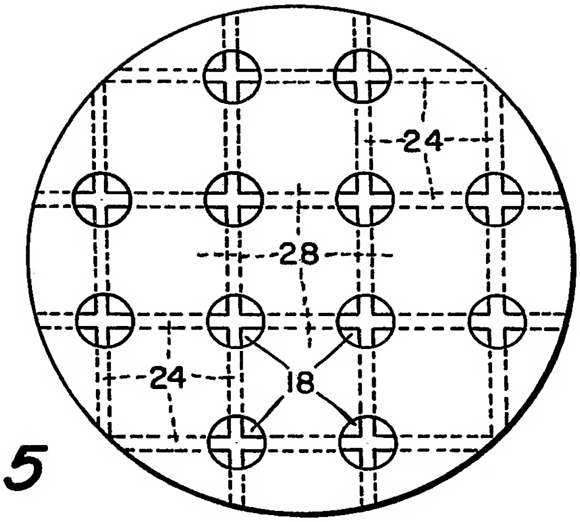


Fig. 5

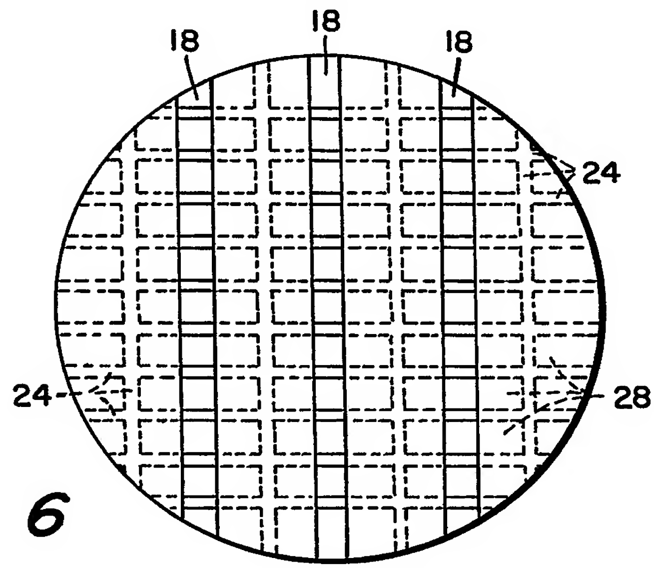
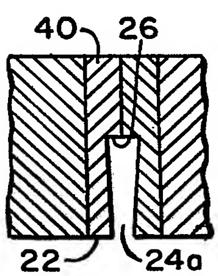
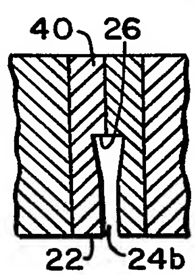


Fig. 6





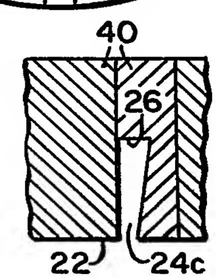


Fig. 7 *Fig. 8* *Fig. 9*